

# **System and Method for Controlling Line Driver Power in a Shared Digital Subscriber Line Modem**

## **Field of the Invention**

The present invention relates generally to communication systems and more particularly to a system and method for controlling the line power requirements of shared Digital Subscriber Line (DSL) transmitters.

## **Background of the Invention**

Asymmetrical Digital Subscriber Line (ADSL) modems offer a high speed alternative (up to 8 Mbps, depending on line conditions) to conventional analog modem technology. United States patent application number 09/135,221, filed, August 17, 1998 and assigned to the same assignee as this application, is incorporated by reference herein. Patent application 09/135,221, hereafter referred to as the 98 application, is directed to a shared asymmetric subscriber line modem. The 98 application introduced the concept of using a single multidrop modem in a central office Digital Subscriber Line Access Multiplexer (DSLAM) to drive multiple subscriber lines. Line sharing was implemented by allocating a small portion of the available bandwidth to a control channel which was used to indicate to a group of client modems which one of the client modems was the intended recipient of a corresponding physical frame of data. This solution resulted in a significant simplification of the digital portion of the ADSL server modem as well as the Digital to Analog converter. This solution requires a separate line driver for each of the subscriber lines. While this is not a major cost consideration, the power

dissipated in each of these line drivers becomes a limiting factor in achieving higher levels of integration on ADSL server line circuit cards.

### **Summary of the Invention**

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The invention contemplates a shared (DSL) modem for generating a physical data frame including a control channel indicating which one of a plurality of client devices connected via subscriber lines to the modem is the intended recipient of the data frame and transmitting the generated physical data frame over the subscriber line connected to that client device. Contemporaneously, transmitting a different physical frame including the same control channel only or the same control channel and a low power signal suitable for synchronization onto the subscriber lines connected to the non selected client devices connected to the SDSL.

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An object of the invention is to substantially reduce the overall power requirements of the line drivers connected to the DSLs by limiting the bandwidth of the signal transmitted to all of the subscriber lines except the subscriber line connected to the intended recipient of a physical data frame.

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Another object of the invention is to enhance data security in a multi-drop modem by deleting the data portion of the physical frame transmitted to the intended recipient from the frames transmitted to all of the lines except the line connected to the intended receiver.

### **Brief Description of the Drawings**

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Figure 1 is an abbreviated version of the transmit portion of the multi-drop

server modem illustrated in Figure 7 of the 98 application; and,

Figure 2, 3 and 4 are block diagrams of different embodiments of the transmitter of a shared multi-drop modem constructed according to the present invention.

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### **Detailed Description of the Invention**

The block diagram illustrated in Figure 1 is a condensed version of only the transmit portion of the shared Digital Subscriber Line (DSL) server modem illustrated in Figure 7 of the 98 application. The receive portion of the shared DSL server modem illustrated in Figure 7 of the 98 application has not been reproduced in Figure 1 since the receiver portion is not relevant to the invention presented in this application.

The shared DSL transmitter 10 includes a block 11 which assembles the data signal (from a source not shown) destined for one of the client stations. Block 11 includes the following functional components illustrated in Figure 7 of the 98 application; digital interface 200, L2 framing and CRC generator 220, packet buffer 222 and client specific block 248.

Block 12 prepares the assembled data in a format suitable for transmission and includes data encoder 224 which scrambles Reed-Solomon codes, interleaves the packets and orders the tones in accordance with client variables previously determined by measuring the characteristics of the DSL over which the client is connected to the shared DSL transmitter 10; symbol buffer 226; symbol mapping and gain scaling 228 which is customized by client specific variables 246; and symbol buffer 230.

Block 13 includes an Inverse Discrete Fourier Transform (IDFT) or an

Inverse Fast Fourier Transform (IFFT) 232 which converts the complex frequency domain symbols to real time domain symbols.

Block 14 includes symbol buffer 234 connected the output of IDFT 232 and a parallel to serial converter 236 for receiving the content of symbol buffer 234.

5 The output of converter 236 is applied to block 15 which includes D/A converter 238 controlled by timing and control 250 and the transmission filter 240. The output of block 15 is applied to line drivers 16-1 - 16-n (not specifically illustrated in the 98 application) which include the isolation buffers 242 of Figure 7 of the 98 application.

10 Data to be transmitted is partitioned into a series of blocks, where each data block consists of all data to be transmitted via a specific physical frame. A physical frame is defined as that portion of a sequence of time-domain samples of the signal transmitted over the line that results from one Inverse FFT operation in a DSL transmitter. The number of bits assigned to each block is a function of the  
15 bit rate negotiated for the link (e.g. number of tone frequency bands, complexity of modulation in each frequency band). Each block is further partitioned into a control field containing control data according to the operation of the subject invention, one or more fields containing user data, and one or more fields used for standard overhead and maintenance functions. The bits from each field are  
20 modulated to generate the corresponding signal components of the physical frame. This physical frame consists of a control channel signal component carrying control data from the control field, one or more data channel signal components carrying user data from corresponding user data fields, and possibly one or more overhead channel signal components carrying data to support various other  
25 overhead and maintenance functions. Note that in actual implementations various

overhead and maintenance fields are transmitted in addition to user data fields, but within the context of the subject invention they can be considered equivalent to additional data fields.

In order to better understand the invention disclosed in this application one needs to compare Figure 1 of this application (the abbreviated version of the transmit portion of Figure 7 in the 98 application) to Figure 2 which will be described below. In Figure 1 data destined for a specific client is enclosed in a frame which includes a control field. The control field includes the identity of the client the frame is directed to. This frame is transmitted, at full power, to all of the clients connected to shared DSL modem. Only the identified client is authorized to receive the frame. The others will normally discard frames not specifically directed to them.

This mode of operation, while satisfactory, is not optimum. Since the signal transmitted to the non-addressed clients are transmitted at full power it places a burden on the design requirements of the circuit card(s) used to implement the shared DSL modem. In addition, the specific client data sent to the other non-addressed clients served by the shared DSL modem poses a potential security risk.

In the block diagram of Figure 2 blocks which are identical in function and structure bear the same reference numerals as used in Figure 1 and blocks which are only structurally the same bear the same reference numeral primed. In Figure 2 blocks 11, 12, 13 and 14 perform the exact same function as the similarly numbered blocks in Figure 1. A control channel 20 receives sufficient information from block 11 to generate a frame which includes the same control channel which was included in the frame generated in block 11 (the data portion included in the frame prepared in block 11 is eliminated). In this regard the information can take

several forms. At a minimum the information must include the identity of the client which is to receive the frame in process. It could include the entire frame prepared in block 11 or some other subset thereof. In any event the control control channel will generate a second frame which includes only a control channel  
5 identical to the control channel generated in block 11 or it may include in addition a low power synchronization field. The control channel sends this truncated frame to block 12' which is structurally identical to block 12. The frame from block 12' passes through blocks 13' and 14' which are structurally identical to block 13 and 14, respectively. Since blocks 11 and 20 are operating on the same input data the  
10 generation of the control channel could utilize common hardware or it could be accomplished by simply stripping the data portion of the frame generated in block 11 in block 20 and adding a low power synchronization signal if deemed prudent.

Control channel 20 sends the identity of the client modem to which the frame is addressed, to a frame select switch 21. Switch 21 receives the inputs from blocks 14 and 14' and sends the frame from block 14 to a TX filter/DAC 15-i  
15 where i is the TX filter/DAC connected to the line driver 16-i which provide a path to the client modem identified in the control channel as the recipient of the frame. Switch 21 sends the frame from 14' to all of the TX filter/DACs except 15-i. With this arrangement full power is only applied to line driver 16-i. The other  
20 line drivers receive only the control channel or the control channel and a low power synchronization signal if the alternative is chosen. This arrangement results in a significant reduction in the total power required in the line driver circuits. Alternatively, switch 21 could be designed to examine the contents of the control channel and perform the described switching function based on that information.  
25 Such a modification would be functionally equivalent.

Instead of driving all client lines with the same signal, the subject invention creates a second frame of time domain samples which contains a subset of the tones used for a full data frame. This is done by eliminating all tone frequency samples modulated with client data, leaving only a small subset of tones (those allocated to the control channel, in addition to those tones required to maintain timing within each remote client device, e.g. pilot tone) as input to a second Inverse FFT (IFFT). Note that it is the signal component from these control tones which is used by each client to determine whether or not a particular data frame is intended for that client. In actual implementation, the fact that most input samples are zero may simplify the computational complexity of the second IFFT. Likewise, further simplification in computational complexity may be possible due to the fact that the control tone samples are used for both IFFT computations. In any case, the time-domain samples resulting from the second IFFT are processed through the same time-domain functions (Parallel-to-serial conversion, adding of cyclic prefix) as used for the data frames. For each frame time, there are then two frame buffers, one holding the time samples of a data frame (including control information) and the other holding time samples of a corresponding frame which includes only control information but no data. In an alternate (functionally equivalent) implementation, control channel content may be processed through some frequency domain functions along with the data content, processed up to the full IFFT, and then the frequency samples modulated with client data can be zeroed out to generate input for the control frame IFFT. Note that regardless of the specific implementation options selected, a single FFT hardware assist unit could likely be shared for both IFFT computations. Alternatively, the two IFFT computations could possibly be implemented as two calls to a common IFFT

subroutine running on a programmable Digital Signal Processor.

Another alternate implementation option would be to define a low-power idle pattern for data tones in the control frame, instead of just setting the amplitudes of these tones to zero. Since constellation points are not equally spaced from the origin in the modulation of each tone, a subset of constellation points can usually be chosen which will average substantially less power than if the same tone evenly distributed its signal across all constellation points. This option may help the client receivers avoid issues relating to the dynamic transitions between data frames and control frames, and may facilitate continued tracking of timing and gain adjustments. Transmitter control functions may also be implemented to group multiple data frames to a single client device prior to sending subsequent data to another client device in order to minimize the number of transitions each link experiences between data frames and control frames. Transmitter control functions may be additionally required to periodically send one or more data frames to each client device even if there is no data to send to the particular client device, in order to maintain timing recovery and gain adjustments in all client devices. To accomplish this, the transmitter would fill one or more data frames with an idle pattern (e.g. scrambled ones) which offers an adequate signal to enable the client receiver to track the required parameters. Regardless of implementation options, each client receiver would compute signal-to-noise ratio (SNR) based on the signal power during reception of a data frame. Otherwise SNR computations might be misleading, and would potentially result in undesirable effects within the receiver. Some type of windowing of the received signal might also be required in order to minimize the transient effects of boundaries between data frames and control frames.



Figure 3 illustrates another implementation in which the transmit filter 31/31' implementation is optimized. If the transmit filter is based on a FIR filter structure, then the filtering for each data and control frame only needs to be done once.

When an isolated set of N time-domain samples representing one physical frame are passed through an FIR filter of length M, the number of output samples expands due to the convolution process to M+N-1 samples. In order to provide functional equivalence with the system depicted in Figure 2, these isolated filter outputs from consecutive frame times must be partially overlapped. This is accomplished in Overlap Add Tx blocks 32-1 to 32-4. Assuming the filter length M is less than the number of samples N in one frame, N-M+1 samples are taken directly from the appropriate filter segment output buffer (either data frame or control frame), but the first M-1 samples are added to the last M-1 samples from the previous frame. It can be shown that this is mathematically equivalent to the separate filter per line illustrated in Figure 2, but results in a significantly lower computational load since only two filters need to be implemented. In this embodiment (as well as the embodiment illustrated in Figure 2) individual D/A converters 33-1 to 33-4 are provided for each DSL.

Figure 4 illustrates another functionally equivalent implementation of the invention in which the transmit filter is pushed outward into the analog domain.

The benefit of this alternative is that only two DAC's 40-1 and 40-2 are required, one for the full data frame and the other for the control frame. One or the other of these signals is routed to each transmit filter, according to which remote client the data frame is addressed to. The individual analog transmit filters 41-1 to 41-4 smooth transitions from control frames to data frames (and visa versa). This implementation results in reduced complexity for the digital portion of the design,

shown in Figure 4 as the Shared DSL Transmitter. The analog portion of the design may be more or less complex than the other alternatives, depending on the relative complexity of the analog transmit filters and analog switches as compared to the per line DACs which are not needed in this design.

5 The foregoing is illustrative of the present invention and is not to be construed as limiting the invention. While several embodiments of this invention have been described in detail, those skilled in this art will readily appreciate that many modifications are possible without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined by the claims.

10 In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and structural and /or functional equivalents thereof. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific  
15 embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the claims appended hereto.